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Reconstructing nutrient criteria for source water areas using reference conditions

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A B S T R A C T

Nutrient concentrations are of concern in most watershed areas that serve as source water for public drinking water due to the high cost of nutrient removal treatment. Yet all nutrients criteria for source watersheds in Taiwan are identical for quality standards and the specific conditions of each source watershed were not considered. Nutrient RCs estimated by statistical methods and land disturbance modeling were applied to the Tamsui River in Taiwan. The results were then used to evaluate the nutrient status of Taipei Water Source Domain, which is located near the upstream portion of Tamsui River. The estimated RCs of NH_3-N, TP, and Total N were 0.03–0.04, 0.019 to 0.036, and 1.22–1.50 mg L^{-1}, respectively. Comparing with current criteria of NH_3-N (0.1 mg L^{-1}), the estimated reference conditions are lower and the criteria could be stricter to maintain sufficient water quality. However, the reference condition of TP estimated by the disturbance modeling (0.03 mg L^{-1}) is higher than current criteria (0.02 mg L^{-1}), leading to a possible loosening adjustment.

1. Introduction

For surface water supplies of drinking water, watershed protection approaches have provided an integrated framework to improve the identification of the highest priority problems and to focus water pollution control effects on the protection of drinking water supplies [1,2]. Many countries have developed assessment tools for protecting watersheds that supply drinking water [2,3] or further established water quality criteria for regulating source water [4]. In Taiwan, two water quality standards, the "Surface Water Classification and Water Quality Standards (hereinafter, Taiwan Surface Water Standards)" and the river pollution index (RPI) [5], can be applied to regulating the water quality of rivers and are also used to evaluate the water quality in watersheds that supply drinking water. However, the water quality in the source water protection area may exhibit different features depending on the specific geographical locations where the watersheds are situated. The uniform criteria for all drinking water protection areas that do not consider the geographical characteristics may not actually reflect the water quality status [6]. In particular, for the nutrient management that results in eutrophication problems, exploring the nutrient background concentration and defining the amount from anthropogenic activities are critical to establish watershed protection plans and prevent increasing the load in water treatment processes for water supply.

The reference conditions (RCs) that are used to provide the biological integrity in biological assessments have been taken to determine the natural background nutrient concentrations in streams [6–12]. Nutrient RCs have been estimated using two main approaches: percentile analysis and disturbance modeling. Percentile analysis identifies nutrient concentration based on analysis of data frequency distributions. Disturbance modeling examines the relationships between nutrient variables and disturbing factors, such as land use type and population density, to establish non-disturbance background concentration [13]. USEPA [12] outlined approaches for establishing the RCs, including the 75th percentile of reference sites and the 5 to 25th percentile of total population. Thereafter, several researchers have used the percentile methods to determine the river nutrient criteria [14–17]. Furthermore, Sánchez-Montoya et al. [18] also used the percentile approach to establish the physio-chemical RCs in Mediterranean streams according to the European Water Framework Directive.

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In addition to the percentile approaches, disturbance modeling has also been used to establish RCs of river nutrients [6,7,19]. The disturbance modeling is a model of multiple linear regressions for evaluating the statistical relationship between river nutrient concentrations and human disturbance [7]. The conditions of the basin environment can return to the undisturbed conditions, which are regarded as the RCs, when the human disturbance is completely removed [20,21]. The disturbance modeling can predict the background nutrient concentrations without abundant reference-site data. Dodds and Oakes [6] used regression models to analyze the relationship between the nutrient concentrations and the disturbance variables (anthropogenic land uses and population densities) to estimate the background concentrations of TN (sum of NO_3^--N, NO_2^--N, and total Kjeldahl nitrogen) and TP in 14 ecoregions. Herlihy and Sifneos [7] applied road densities, population densities, anthropogenic land uses, and riparian disturbance indices as disturbance factors to evaluate the background TN and TP concentrations in three ecoregions.

In northern Taiwan, the Taipei Water Source Domain (TWSD) located upstream of the Tamsui River is the most important source water protection area. According to the monitoring data in the past six years (2005–2010), the nutrient concentrations in the area often exceeded the Taiwan surface water standards. However, current standards are not established specifically to source water areas; nor do they consider the geographical features for each watershed. This study uses the TWSD as a case study to evaluate the source water quality by comparing with the nutrient RCs which were estimated by percentile and disturbance modeling methods. Additionally, the results provide suggestion for revising the current water quality standards.

2. Materials and methods

2.1. Study area

The TWSD, a source water protection area delineated in 1984 and managed by the Taipei Water Management Office (TWMO), is located in northern Taiwan (Fig. 1). The Feitsui Reservoir, which provides drinking water to approximately 5 million people in the Taipei metropolitan area, is situated within this domain. The area of the TWSD is 717 km^2. Over 92% of the area is forested, 2% is agricultural land, and approximately 1% is urban and transportation uses. The activities of land-use, mining, forestry and recreation are strictly limited in the area. As a result, the nutrients status in this area is better than that of the midstream and downstream regions in the Tamsui River. The average concentrations of TP and NH_3-N in the TWSD are 0.023 and 0.02 mg L^{-1}, which are lower than the average concentration of TP and NH_3-N in the Tamsui River Basin (0.162 and 0.98 mg L^{-1}, respectively). We adopted the monitoring sites in the TWSD as reference sites to estimate the background nutrient concentrations for the Tamsui River and later compared the derived criteria with the current water quality standards and monitoring data to discuss the suitability of the requirements of the regulations.

The Tamsui River is 159 km long and has an area of 2726 km^2, whose main source is situated at the latitude 24°26′11.3″ N and at the longitude 121°15′56.6″ E in the northern Taiwan. The average annual precipitation in the Tamsui River Basin can vary from 2100 mm in the estuary to 5000 mm in the mountains. The fluctuating flow condition obtained from a hydraulic station in the central part of the basin is shown in Fig. 2. Most peak flow occurred during the typhoon season from July to September. There are approximately 9 million people, 39% of the overall population in Taiwan, living in the basin. Approximately 70% of the area is forested; 17% of the area is for urban and transportation uses; 6% is for agricultural use.

2.2. Data collection

The data used to establish the RCs of the nutrients came from two sources. The first source was from the 38 sites of Taiwan EPA's monitoring sites distributed in the Tamsui River Basin, and the other source was from the 23 sites monitored by the TWMO (Fig. 1). Because the area managed by TWMO is assumed pristine or the least-disturbed upstream watersheds, the water quality there is classified into Category A according to the Surface Water Standards and classified into the unpolluted or slightly polluted class according to the Taiwan RPI (Table 1).

The RCs of NH_3-N, TP, and TN were analyzed in this study. The NH_3-N and TP concentrations were monitored monthly from 61 sites (Taiwan EPA and TWMO) from 2005 to 2010. The TN was monitored monthly from 38 Taiwan EPA sites from 2002 to 2006. If any monitored record is reported as “not detected”, half of the detection limit is used to replace the record for further analyses. The detection limits of NH_3-N, TP were 0.1 and 0.006 mg L^{-1}, respectively.

2.3. The percentile values from the monitoring sites

The 75th percentile of the reference sites is one of the reference-site approaches for establishing the background nutrient criteria. The USEPA [12] suggested that authorities could use the 75th percentile values of the nutrient concentration distribution in reference streams as the standards for regulating river nutrients. This approach was adopted in this study to determine the candidate criteria of the NH_3-N and TP concentrations in the Tamsui River with the data from the 23 reference sites. Because Taiwan EPA did not monitor TN for the reference sites, no TN criterion was suggested by this 75th percentile approach.

When the reference sites are few or not available, the USEPA [12] provided the 5 to 25th percentiles of the total population sites as a surrogate instead of the 75th percentile of the reference sites. This approach chooses one percentile from the 5 to 25th percentiles of the nutrient concentration distribution of the general sites as the candidate nutrient criteria. In this study, the 5 to 25th percentiles of the population was calculated with the data of 61 sites (from the entire basin and from the reference sites) to estimate the NH_3-N and TP background concentrations. However, the TN criterion was suggested by the data of the 38 Taiwan EPA sites.

2.4. Disturbance modeling

Disturbance modeling establishes the statistical relationship between the river nutrient concentrations and the human disturbance levels to predict the natural background nutrient concentrations. The median of the monthly nutrient concentrations monitored from 61 sites was modeled with multiple linear regressions as a function of the disturbance variables [7]. All the nutrient concentrations were log transformed for normal distributions (Kolmogorov-Smirnov test, $p > 0.05$) and to avoid negative intercepts that lead to negative concentrations [6]. The intercepts of the regression models represent the nutrient concentrations in the absence of anthropogenic land uses and other human disturbance variables.

The disturbance factors used in this study include the percentage of paddy land, upland, orchard land, husbandry land, urban land, transportation land, and the population densities; however, one variable was deleted if any two variables were highly correlated ($r > |0.80|$) to avoid collinear problems. The multiple linear

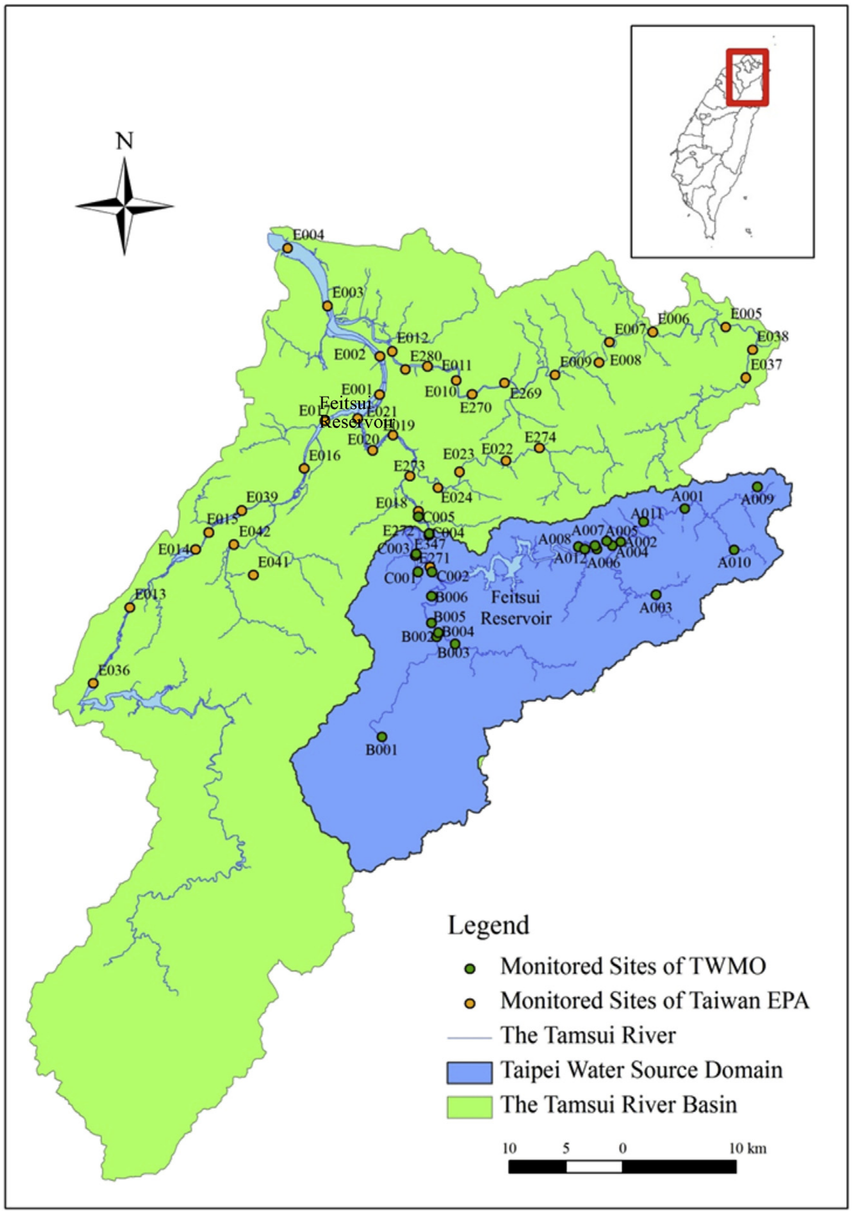

Fig. 1. Study area and the location of general and reference sites determined in this study.

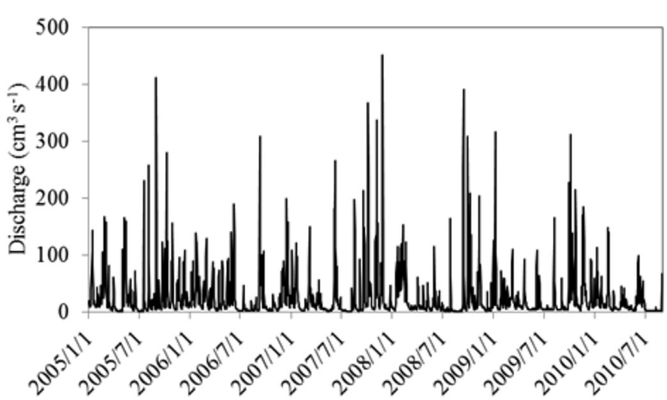

Fig. 2. The fluctuating flow condition in the central of basin.

Table 1
Water quality standards for nutrients in Taiwan.

Unit: mg L^{-1}		
Criteria[a]	TP	NH_3-N
Category A of Taiwan surface water standards[b]	Less than 0.02	Less than 0.1
Non (slightly) polluted class of Taiwan RPI[c]	No regulation	Less than 0.5

[a] TN are not regulated by these two standards.
[b] Category A of the Taiwan surface water standards means that water bodies may be used for public water (after disinfection), swimming and as other lower categories' water bodies.
[c] RPI: River pollution index.

regressions were modeled with SAS 9.2, and the spatial analysis tools in ArcGIS 9.3 was used to divide the Tamsui River Basin into 61 sub-watersheds dominated by each site in calculating the disturbance variables. Detailed values of the disturbance factors for the 61 sub-watersheds can be found in the Table A1 in the supplemented material.

3. Results and discussion

3.1. Estimated RCs of nutrients

Table 2 presents the percentile values for the NH_3-N, TP, and TN. The nutrient concentrations estimated with the 75th percentile of reference sites are closer to the concentrations predicted with the 25th percentile of the total population than those predicted with the 5th percentile of the total population sites. In addition, the values derived from the 5th percentile are much lower than the natural conditions mentioned in literature, such as the TP level of 0.02 mg L^{-1} [21]. According to the guidelines of the 5 to 25th percentiles of the population [12], the Tamsui River Basin may not be entirely polluted because the 25th percentile is more appropriate to this area and the 5th percentile is unreasonable. The 75th reference-site percentiles of the NH_3-N and TP correspond to the 62nd and 51st percentiles of the general population, respectively. This result indicates the water quality in the TWSD may have been contaminated by human activities; consequently, assuming all sampling stations in TWSD as reference sites may not be a reasonable inference and may result in an inappropriate background nutrient concentration for the Tamsui River Basin or for use in regulating the source water quality.

Table 3 presents the correlation coefficients between the disturbance factors. The percentage of transportation land was deleted in the following regression because of highly correlated with urban land and population density. Table 4 shows the multiple linear regression models for these nutrient components. The coefficients of determination (adjusted R^2) of the NH_3-N and TP regression model are 0.732 and 0.761, respectively, meaning that the selected factors could describe most of the variability (adjusted $R^2 > 0.7$) of the NH_3-N and TP concentrations in the Tamsui River. For the TN regression results, the disturbance variables can only explain approximately half variability of the TN concentrations in the Tamsui River (adjusted $R^2 = 0.565$). The results indicate that the % orchard, % husbandry, and % urban are positively correlated with the concentration of NH_3-N, TP, and TN, and the relationship between % husbandry and nutrient level is the most strong. However, % paddy and % upland were negatively correlated with the nutrient concentrations. This result suggests that a small percentage of land-use (less than 1%) may not exhibit effects on the disturbance model. Table A2 presents the coefficients and p values for the regression processes. The results revealed that the correlations of % orchard and % urban were found to be statistically significant with TP, NH_3-N, and TN. The correlation of % husbandry was statistically significant with TP and NH_3-N, but not with TN. However, the correlations of % paddy with the three nutrient concentrations were shown not to be statistically significant.

As shown in Table 4, the concentrations derived from the 75th percentile of reference sites for NH_3-N and TP are both higher than those from the 25th percentile of population and the disturbance modeling. For the 25th percentile of the population approach, the estimated concentrations are close to those of the disturbance modeling; in particular, the NH_3-N concentrations obtained from these two methods are nearly identical (0.030 and 0.029 mg L^{-1}). The TP concentration of the 25th percentile of population is lower than that of disturbance modeling. However, the TN concentration of the 25th percentile of population is higher than that of the disturbance modeling because only middle and downstream data are used in the analysis (38 sites of the Taiwan EPA).

3.2. Comparison between the estimated values and the current standards

Table 2 shows that the NH_3-N background concentrations obtained from the 75th reference-site percentile (0.04 mg L^{-1}), the 25th percentile of the total population (0.03 mg L^{-1}), and the disturbance modeling (0.029 mg L^{-1}) are all far lower than the unpolluted or slightly polluted class (Category A) of the Taiwan EPA water quality standards (0.1 mg L^{-1}) and the Taiwan RPI (0.5 mg L^{-1}). However, besides the TP concentration derived from the 25th percentile of population (0.019 mg L^{-1}) being nearly identical with the Category A class of Taiwan EPA surface water standards (0.020 mg L^{-1}), the TP concentrations of the 75th reference-site percentile (0.035 mg L^{-1}) and the disturbance modeling (0.027 mg L^{-1}) are both higher than the standards. The results indicate that the monitoring data from TWMO could not meet the Taiwan EPA standard of more than 75% frequency for TP. Conditions that exceed the current Category A standard of TP for the TWSD has been of considerable concern to the appropriate authorities recently. It is important to explore the background conditions for the area to determine whether more strict protection measures should be adopted in the watershed. Therefore, if the nutrient concentrations estimated by this study represent the RCs of the unpolluted or slightly polluted streams in the Tamsui River Basin, which are regarded as the background concentrations, then the current TP standard (0.02 mg L^{-1}) for Category A in the Taiwan EPA standard seems too strict for the upstream of Tamsui River (TWSD). Furthermore, the loading of nitrogen in the area seems well controlled because the derived NH_3-N background values from this study are far lower than those of the two current standards. Ideally, RCs of water quality should be re-evaluate every three to five years to verify the background concentrations defined in this study, and to allow for more rigorous statistical estimates of reference site variability.

3.3. Validation of the reference-site assumption

Twenty-three sites within TWSD were assumed as reference sites in the beginning; therefore, the assumption was validated with the background nutrient concentrations predicted by the disturbance modeling. Taking the criteria established with the disturbance modeling as standards, Fig. 3 presents the conformity percentage that the NH_3-N and TP concentrations of all sites in the Tamsui River. The NH_3-N and TP percentages of 2 sites (B002 and C005) are both lower than 50%. We assumed that the 50% conformity percentage was the screening benchmark for selecting reference sites; in this case, sites B002 and C005 will not be suitable as reference sites. This result indicates that the environmental management of the tributaries where these two sites are located may not sufficient.

Table 2
Percentile values for background nutrient concentrations.

Unit: mg L^{-1}			
Percentile values	NH_3-N	TP	TN
Reference-site 75th percentile	0.04	0.036	-[a]
Population 5th percentile	0.005	0.003	0.73
Population 25th percentile	0.03	0.019	1.50

[a] No monitoring data.

Table 3
Correlation coefficients between the disturbance factors.

	Paddy land (%)	Upland (%)	Orchard land (%)	Husbandry (%)	Transportation land (%)	Urban land (%)	Population density (/km^2)
Paddy land (%)	1.000	–	–	–	–	–	–
Upland (%)	0.205	1.000	–	–	–	–	–
Orchard land (%)	0.021	0.225	1.000	–	–	–	–
Husbandry (%)	0.383	0.140	0.047	1.000	–	–	–
Transportation land (%)	−0.018	−0.079	−0.165	0.005	1.000	–	–
Urban land (%)	0.081	−0.131	−0.104	0.071	0.940	1.000	–
Population density (/km^2)	−0.048	−0.142	−0.096	0.027	0.855	0.744	1.000

Table 4
Multiple linear regression models used to estimate the NH_3-N, TP and TN background concentrations in the Tamsui River[a].

Parameter	Disturbance modeling	Adjusted R^2	SE[b] of intercept	Background concentration[c] (mg L^{-1})
H_3-N	$Log_{10}(NH_3\text{-}N)$[d] $= -1.53076 - 0.06314$ (% paddy) $- 0.02126$ (% upland) $+ 0.09616$ (% orchard) $+ 1.53685$ (% husbandry) $+ 0.04455$ (% urban)	0.732	0.111	0.029
TP	Log_{10} (TP)[d] $= -1.57344 - 0.02443$ (% paddy) $- 0.01407$ (% upland) $+ 0.06225$ (% orchard) $+ 0.79458$ (% husbandry) $+ 0.02679$ (% urban)	0.761	0.062	0.027
TN	Log (TN)[d] $= 0.08524 - 0.02953$ (% paddy) $- 0.01562$ (% upland) $+ 0.03159$ (% orchard) $+ 0.54201$ (% husbandry) $+ 0.01421$ (% urban)	0.565	0.080	1.217

[a] The p-value of the three models are all lower than 0.0001.
[b] SE means the standard error.
[c] Background concentration can be derived from the intercept, e.g., background concentration for NH_3-N = 10^(−1.53076) = 0.029.
[d] The p values for the regression models can be found in Table A2 in the supplementary material.

Fig. 3 also shows the conformity percentages of 38 sites outside the TWSD. If the sites with higher percentages than 50% will be selected as additional candidate reference sites, site E039 can be regarded as a reference site outside the TWSD for TP (Fig. 3B), while no additional site can be selected for NH_3-N (Fig. 3A). Therefore, if all 61 sites are used to establish the RCs for the Tamsui River again, sites B002 and C005 should be removed from the reference sites, while site E039 can be included. After adjustment and

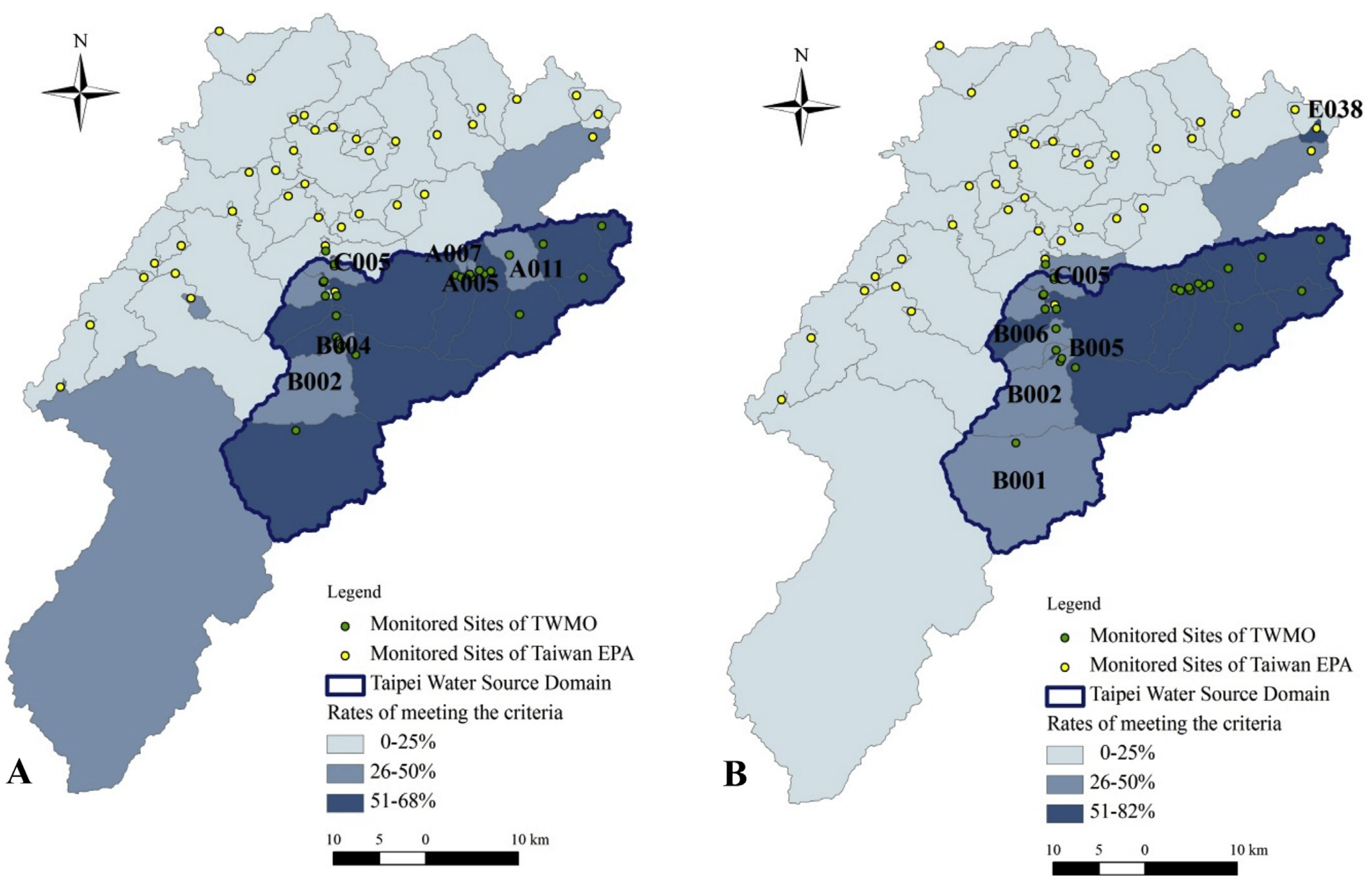

Fig. 3. Rates that the historical concentrations of monitored sites meet the criteria: (A) NH_3-N (B) TP.

recalculation, we can obtain the adjusted 75th reference-site percentiles. In addition, the adjusted 75th reference-site percentile of NH_3-N (0.04 mg L^{-1}) is consistent with the former result, and the 75th reference-site percentile of TP slightly declines (0.034 mg L^{-1}). These results may suggest that the reference sites or the reference-stream data used in this study are adequate, which leads to similar results even when few sites are removed or added. Besides this validation of the reference sites, verification of RCs could be conducted by collecting more monitoring data in the future. According to the suggestion of USEPA [12], RCs for specific area can be used as a baseline to protect aquatic ecosystem and need to be re-examined periodically.

4. Conclusions

Setting reasonable water quality standards is crucial to protect water resources, especially for the surface water providing drinking water source. This study utilizes the RCs approach to evaluate the current nutrient criteria for a source water protection area (TWSD) located in the watershed upstream of northern Taiwan. Our findings indicate that the predicted RCs for NH_3-N, TP, and TN range from 0.03 to 0.04, 0.019 to 0.035, and 1.22–1.50 mg L^{-1}, respectively. In comparison with the estimated reference nutrient conditions, the current nutrient status in TWSD has been affected by human activities and needs adopting stricter protection measures. Current standards for the present source water protection area (the Category A of the surface water) may need to be revised because the estimated NH_3-N RCs are far lower than the current standard and the TP RCs are worse. Specific nutrient criteria for source water areas are necessary because natural conditions for each source area may be completely different. RCs for streams are important indicators for watershed management policies. However, reference sites determination need to be further discussed in Taiwan for distinctive geographic features.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.serj.2016.05.002.

References

[1] Chiueh PT, Shang WT, Lo SL. An integrated risk management model for source water protection areas. Int J Environ Res Public Health 2012;9:3724–39.
[2] Peckenham JM, Schmitt CV, McNelly JL, Tolman AL. Linking water quality to the watershed: developing tools for source water protection. J Am Water Works Ass 2005;97:62–9.
[3] Emelko MB, Silins U, Bladon KD, Stone M. Implications of land disturbance on drinking water treatability in a changing climate: demonstrating the need for "source water supply and protection" strategies. Water Res 2011;45:461–72.
[4] Hurley T, Sadiq R, Mazumder A. Adaptation and evaluation of the Canadian council of ministers of the environment water quality index (CCME WQI) for use as an effective tool to characterize drinking source water quality. Water Res 2012;46:3544–52.
[5] Lai YC, Tu YT, Yang CP, Surampalli RY, Kao CM. Development of a water quality modeling system for river pollution index and suspended solid loading evaluation. J Hydrol 2013;478:89–101.
[6] Dodds WK, Oakes RM. A technique for establishing reference nutrient concentrations across watersheds affected by humans. Limnol Oceanogr-Meth 2004;2:333–41.
[7] Herlihy AT, Sifneos JC. Developing nutrient criteria and classification schemes for wadeable streams in the conterminous US. J N Am Benthol Soc 2008;27:932–48.
[8] Martins FA, Janeiro J, Gabriel S, Venancio A, Neves R. Integrated monitoring of South Portugal water bodies: a methodology towards WFD. Water Sci Technol 2009;60:1979–88.
[9] McDowell RW, Snelder TH, Cox N, Booker DJ, Wilcock RJ. Establishment of reference or baseline conditions of chemical indicators in New Zealand streams and rivers relative to present conditions. Mar Freshw Res 2013;64:387–400.
[10] Pardo I, Gómez-Rodríguez C, Wasson JG, Owen R, van de Bund W, Kelly M, et al. The European reference condition concept: a scientific and technical approach to identify minimally-impacted river ecosystems. Sci Total Environ 2012;420:33–42.
[11] Smith RA, Alexander RB, Schwarz GE. Natural background concentrations of nutrients in streams and rivers of the conterminous United States. Environ Sci Technol 2003;37:3039–47.
[12] USEPA. Nutrient Criteria: Technical Guidance Manual, Rivers and Streams. Washington, DC: US Environmental Protection Agency; 2000.
[13] Evans-White MA, Haggard BE, Scott JT. A review of stream nutrient criteria development in the United States. J Environ Qual 2013;42:1002–14.
[14] Morgan RP, Kline KM, Churchill JB. Estimating reference nutrient criteria for Maryland ecoregions. Environ Monit Assess 2013;185:2123–37.
[15] Santoro ED, Limbeck RL. Nutrient Criteria Strategy for the Tidal and Non-tidal Delaware River. West Trenton, NJ: Delaware River Basin Commission; 2008.
[16] Suplee MW, Varghese A, Cleland J. Developing nutrient criteria for streams: an evaluation of the frequency distribution method. J Am Water Resour As 2007;43:453–72.
[17] Huo SL, Ma CZ, Xi BD, Su J, He ZS, Li X. Establishing water quality reference conditions for nutrients, chlorophyll a and Secchi depth for 7 typical lakes in arid and semiarid ecoregion, China. Environ Earth Sci 2015;73:4739–48.
[18] Sánchez-Montoya MD, Arce MI, Vidal-Abarca MR, Suarez ML, Prat N, Gomez R. Establishing physico-chemical reference conditions in Mediterranean streams according to the European water framework directive. Water Res 2012;46:2257–69.
[19] Heiskary SA, Bouchard RW. Development of eutrophication criteria for Minnesota streams and rivers using multiple lines of evidence. Freshw Sci 2015;34:574–92.
[20] Dodds WK. Trophic state, eutrophication and nutrient criteria in streams. Trends Ecol Evol 2007;22:669–76.
[21] Stoddard JL, Larsen DP, Hawkins CP, Johnson RK, Norris RH. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecol Appl 2006;16:1267–76.